Depending on the complexity of the accident, the charts may result in a very large complex sequence of events covering several walls in the "command center." For the purpose of inclusion in the investigation report and closeout briefings, the chart is generally summarized. Note that "assumed conditions" appear in the final chart. These are conditions the board presumed affected the accident sequence, but could not substantiate with evidence.

Conducting the Analysis. Initial events and causal factors analysis can begin when the board believes the chart contains adequate detail. This preliminary analysis can guide the board in evidence collection and lines of inquiry for witness interviews. As more evidence is collected, additional analyses can be conducted until causal factors are identified.

7.3.2 Barrier Analysis

Barrier analysis (sometimes called barrier and control analysis or energy trace and barrier analysis) is based on the premise that an energy flow is associated with all accidents. For an accident to occur, there must be:

- **A hazard**, which comes into contact with
- **A target**, because
- **Barriers or controls** were unused or failed.

Barriers are developed and integrated into a system or work process to protect personnel and equipment from unwanted energy flows (see Figure 7-3). Three common types of barriers are shown in Figure 7-4.

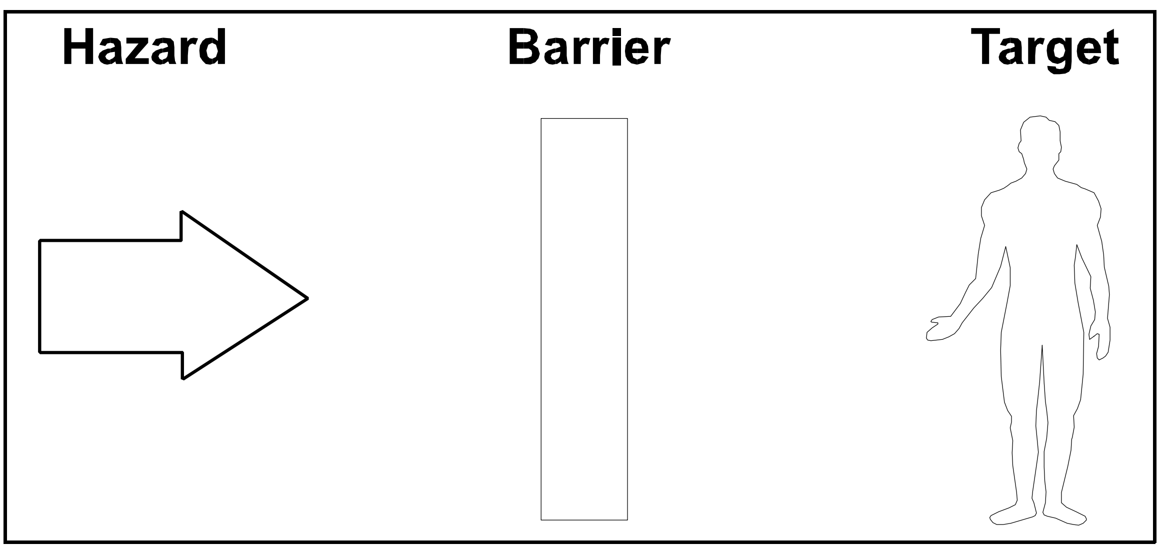

Figure 7-3. Barriers are intended to protect personnel and property against hazards.

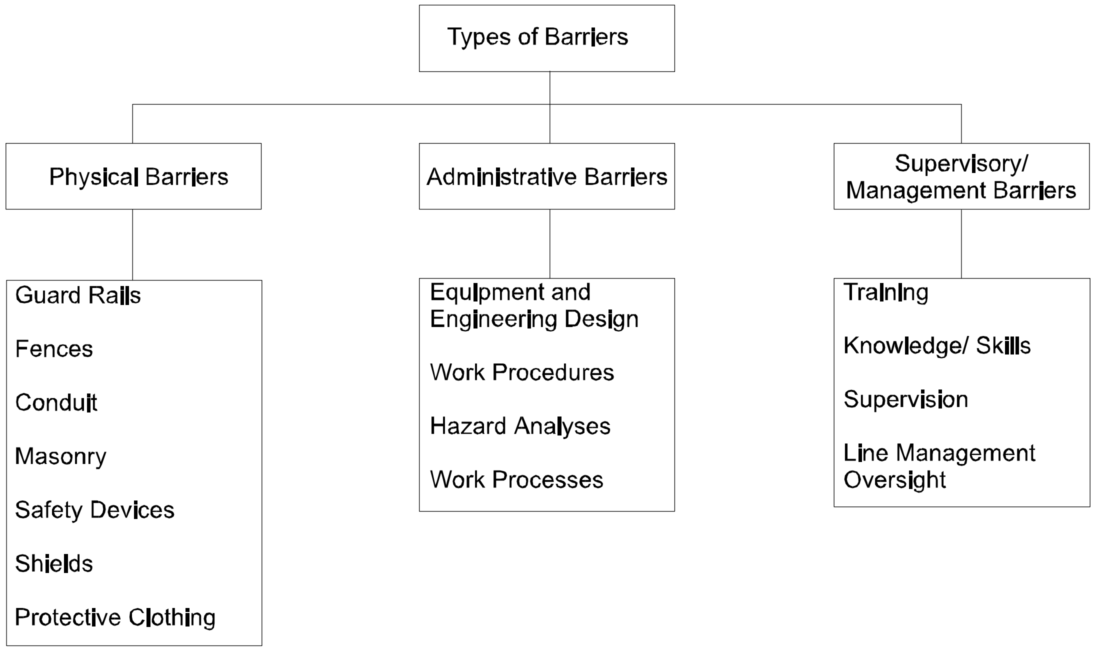

Figure 7-4. Three types of barriers may be integrated into work processes.

Investigators use the barrier analysis technique to identify hazards associated with an accident and barriers and controls that should have been in place to prevent it. Hazards are the potential for an energy flow to result in an accident or otherwise adverse consequence. Energy flow is the transfer of energy from its source to another destination. This transfer of energy can be either wanted or unwanted. For example, the flow of electricity through an electrical cable to a piece of equipment is a desired energy flow. A worker coming into contact with that electricity is an undesired energy transfer.

For the purposes of this technique, **energy** is defined as kinetic, biological, acoustic, chemical, electrical, mechanical, potential, electromagnetic, thermal, radiation, or any other energy source. A **target** is a person or object that an unwanted energy flow may damage, injure, or result in a fatality. **Barriers** are anything used to control, prevent, or impede energy flows.

Investigators evaluate: (a) the adequacy of existing barriers and controls to determine why they were not used or failed, and (b) whether barriers were installed, and if not, why not. By identifying energy sources and failed or unused barriers, a logical sequence of barrier and control measures can be developed to help investigators identify causal factors.

The Basic Barrier Analysis Process

- **Define Final Loss Event** — the events that result in loss or damage (e.g., injury sustained, equipment damaged)
- **Identify Barriers** — both barriers that were in place and those that should have been in place; note that more than one barrier may be associated with each unwanted event
- **Evaluate Purpose of Barrier** — describe the purpose of the barrier and its intended function in eliminating hazardous conditions
- **Evaluate Barrier's Performance** — describe how and why the barrier failed, and the consequences of the failure
- **Validate Analysis** — ensure that results are consistent with or complementary to the results of other analytic techniques

When evaluating the effectiveness of barriers and controls, investigators should understand the function, location, and features of each barrier. Sources of needed data for a barrier analysis include:

- Preliminary drawings of equipment
- Systems or facilities
- Hazard analysis results
- Maintenance procedures
- Operational procedures
- Site maps.

The minimum data needed to perform a barrier and control analysis includes:

- Facts and evidence in a logical sequence as they occurred
- Identification of all relevant hazards
- Identification of all relevant barriers and controls
- Facts regarding the function of each barrier and control.

A barrier's exact function and location should be considered after determining how energy sources and targets can come together and what is required to keep them separated. Obvious barriers and controls are those placed directly on the hazard (e.g., a guard on a grinding wheel); those placed between a hazard and a target (e.g., a railing on a second-story platform); or those located on the target (e.g., a welding helmet). Barriers and controls such as those defining the exposure limits required to minimize harm to personnel are more obscure. Therefore, investigators must cross-validate the results of the barrier analysis with other core analytic techniques to ensure that all failed, unused, or uninstalled barriers are identified. Accurate and complete causal factors of the accident can then be determined.

Constructing a Worksheet. A barrier and control analysis worksheet is a useful tool in conducting a barrier analysis. A blank worksheet is provided at the end of this section. Table 7-2 illustrates a worksheet that was partially completed using data from the electrical accident. Steps used for completing this worksheet are provided below.

Table 7-2. Barrier Analysis Worksheet

Hazard	Direct Barrier or Control Failure	Possible Contributing Factors to Barrier or Control Failures	Possible Root Causes of Failures	Loss or Potential Loss Event	Evaluation
Contact with 13.2 kV electric cable	Failure of design to identify electrical cable at sump location	Architect/engineering firm was not tasked to provide engineering drawings or specifications The design was only intended to provide preliminary information As-built drawings were not used to identify utility lines	Environmental Group was not knowledgeable in project management to request engineering designs or specifications	Injury or death from contact with 13.2 kV cable	A planning organization was given responsibility for the project in order to meet Environmental Protection Agency (EPA) schedule commit-ments
	Failure of worker to detect electrical cable during excavation	Color and texture of concrete and tuff are similar Compressive strength are similar for concrete and tuff	Job specific hazard awareness training		Hazard awareness was not adequately provided to the cement mason foreman
	Failure of excavation procedure to identify electrical cable	Confusion among crafts person-nel, foremen, and supervisors on requirements for an excavation permit indoors Facility Risk Management Group review fails to identify the need for an excavation permit during the service request process Water Quality Group did not know of excavation permit requirement	Implementation and training on procedures Lack of understanding of responsibilities		Implementation of procedures was not enforced ESH personnel assumed that a more detailed specific safety and health review would be performed

Step 1: Identify the hazard. Record information in column one. *"Contact with 13.2 kV electric cable."*

Step 2: Identify each barrier and control failure. Record in column two. *"Failure of design to identify electrical cable at sump location. Failure of worker to detect electrical cable during excavation. Failure of excavation procedure to identify electrical cable."*

Step 3: Identify the most probable contributing factors to each failure listed. Record in column three. *"Architect/engineering firm was not tasked to provide engineering drawings or specifications. The design was only intended to provide preliminary information. As-built drawings were not used to identify utility lines."*

Step 4: Identify and consider possible root causes underlying the failure. Record in column four. *"Environmental group was not knowledgeable enough in project management to request engineering designs or specifications."*

Step 5: Describes the loss that resulted as a result of the barrier/control failure. Record in column five. *"Injury or death from contact with 13.2 kV cable."*

Step 6: Evaluate the cause of the failure. Record evaluation in column six. *"A planning organization was given responsibility for the project in order to meet Environmental Protection Agency (EPA) schedule commitments."*

In conducting barrier analysis, it is often useful to employ results of supplementary techniques such as change analysis or root cause analysis. For example, in identifying all relevant barriers and controls to determine which failed, it is often more difficult to obtain systematic information on administrative controls than it is to identify existing barriers. These supplementary techniques can be used to more systematically identify and examine possible contributing and root causes leading to each failure.

TIP

While the barrier analysis technique helps identify multiple failures, such failures may not always lead to contributing and root causes. However, the results of barrier analysis can directly feed into and facilitate root cause analysis.

Analyzing the Results. The results of barrier analysis are first derived and portrayed in tabular form, then summarized graphically to illustrate, in a linear manner, the barriers that failed to prevent an accident. Results from this method can also reveal what barriers should have or could have prevented an accident.

In the tabular format, individual barriers and their purposes are defined. Each is considered for its effectiveness in isolating, shielding, and controlling an undesired path of energy.

Figure 7-5 provides an example of a barrier analysis summary. This format is particularly useful for illustrating barriers that failed and enabled the injured party to come into contact with the energy source, thus allowing the accident. Such a summary chart is an effective graphic in closeout briefings and in the final report.

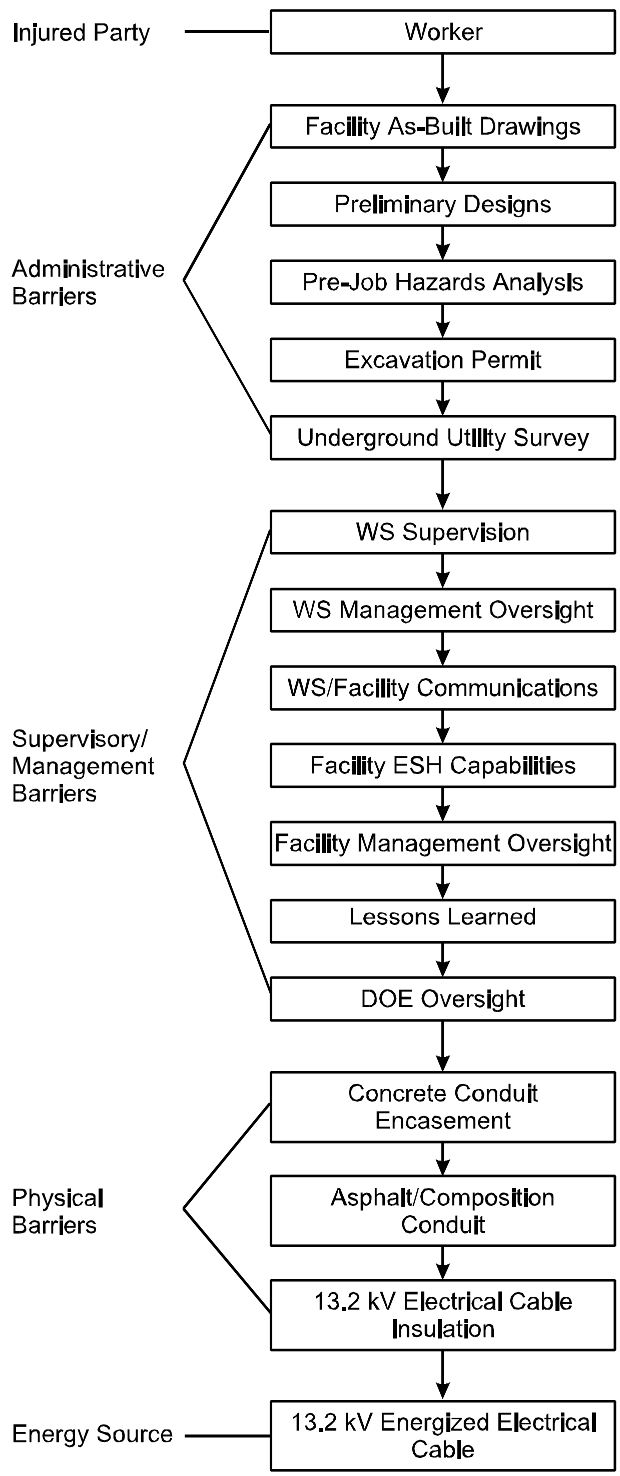

Figure 7-5. Summary results from a barrier analysis show the types of barriers involved.

7.3.3 Change Analysis

Change is one of the most important factors in the cause of accidents. Change is anything that disturbs the “balance” of a system operating as planned. Change is often the source of deviations in system operations. Change can be planned, anticipated, and desired, or it can be unintentional and unwanted. It is an integral and necessary part of daily business; for example, requirements change, procedures change, policies and directive change, the personnel performing certain tasks change (i.e., personnel turnover). Change can improve efficiency, productivity, and safety, or can result in errors, loss of control, and accidents.

TIP
Change analysis is particularly useful in identifying obscure contributing causes of accidents that result from changes in a system.

Change analysis examines planned or unplanned changes that cause undesired outcomes. In accident investigation, this technique is used to examine an accident by analyzing the difference between what is expected or planned (i.e., an accident-free situation), and the actual sequence of events. The person performing change analysis systematically identifies specific elements or differences that caused the outcome of a certain task to deviate from the anticipated outcome. For example, why would a system that operates correctly 99 times out of 100 fail to operate as expected one time?

Conducting Change Analysis. Change analysis is a relatively simple technique to employ. As illustrated in Figure 7-6, it consists of six steps. The last step, in which investigators combine the results of the change analysis with the results from other methods, is critical to developing a broad and comprehensive understanding of the accident.

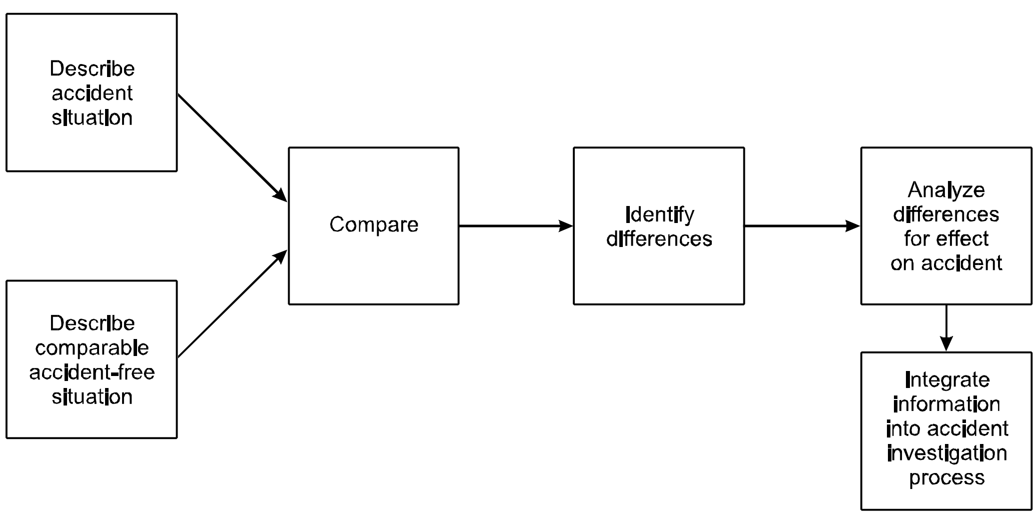

Figure 7-6. The change analysis process is relatively simple.

During the application of change analysis, investigators identify *changes* as well as the *results* of those changes. The distinction is important, because identifying only the *results* of change may not prompt investigators to identify all causal factors of an accident.

The results of a change analysis can stand alone, but are most useful when they are incorporated with other methods, such as the events and causal factors analysis, in searching for direct, contributing, and root causal factors.

To conduct a change analysis, the analyst needs to have a comparative situation. This comparative situation can be:

- The same situation, but accident-free
- A comparable situation at another facility or DOE site
- A model or ideal situation (i.e., as designed or engineered).

Generally, it is recommended that boards compare the accident sequence to the same situation in an accident-free state—the operation prior to the accident—to determine differences and thereby identify accident causal factors. In order for the comparison to be effective, investigators must have sufficient information regarding this comparative situation.

TIP
In change analysis, differing events and conditions are systematically reviewed and analyzed to determine potential causes.

The following data sources can be a starting point for acquiring a good working knowledge of the system, facility, or process under study prior to the accident or event; however, the list of input requirements should be tailored to fit the specific circumstances and needs of the investigation:

- Blueprints
- Equipment description documents
- Drawings
- Schematics
- Operating and maintenance procedures
- Roles and responsibilities
- Job/task descriptions
- Personnel qualifications
- Results of risk analysis
- Performance indicators
- Personnel turnover statistics.

Depending on the complexity of the accident and the method that is familiar to the investigator or analyst, one of several worksheets can be used to record data and the analytic results. One is presented at the end of this section for reference, but the use of other worksheets is acceptable.

Table 7-3 lists questions that should be considered for inclusion in a change analysis worksheet. Note that the worksheet should be tailored to include any conditions, events, or factors pertinent to the accident under investigation. Table 7-4 shows a partially completed change analysis worksheet containing information from the case study to demonstrate the change analysis approach. The worksheet enables the user to compare the "accident situation" with the "accident-free situation" and evaluate the differences or variances to determine each item's effect on the accident.

A change analysis summary, as shown in Table 7-5, is generally included in the accident investigation report. It contains a subset of the information contained in the change analysis worksheet. The differences or changes identified can generally be described as causal factors and should be noted on the events and causal factors chart and used in the root cause analysis, as appropriate.

Table 7-3. Considerations for Completing the Change Analysis Worksheet.

WHAT?

What is the accident?
What occurred to create the accident?
What occurred prior to the accident?
What occurred following the condition or accident?
What operational activities were under way when the accident occurred?
What maintenance activity was under way when the accident occurred?
Was there a training activity under way when the accident occurred?
What equipment was involved in the accident?
What barriers should have been in place to prevent the accident?
What barriers were in place but failed to stop the unwanted transfer of energy?

WHEN?

When did the accident occur?
What was the facility's status at the time of occurrence?
What was the facility's status at the time the accident was identified?
Did the time of day have an effect on the condition? Personnel availability?
Did the accident involve shift-work personnel?
For how many continuous hours had any involved personnel been working?

WHERE?

Where did the accident occur?
What were the physical conditions in the area?
Where was the accident identified?
Was location a factor in causing the accident?

WHO?

Who were the personnel involved in the accident?
Which personnel witnessed the accident?
Which personnel reported the accident?
Which personnel ameliorated the accident?
What was the training/qualifications of the personnel involved?
Who was supervising this activity?

HOW?

Was the accident caused by an inappropriate action?
Was procedure use a factor in the condition? If so:
- Did the procedure have sufficient detail?
- Did the procedure have sufficient warnings and precautions?
- Did the procedure cover work tasks in proper sequence?

Table 7-4. Change Analysis Worksheet.

Factors	Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
WHAT Conditions, occurrences, activities, equipment	1. Design and ES&H reviews were not performed. 2. Established review process was bypassed. 3. Hazards associated with the work being performed were not identified. No review of as-built drawings. No excavation permit. No underground utility survey.	1. Project design and ES&H review are performed by appropriate groups to ensure adequate review and the safety and health of employees. 2. Construction packages are approved by facilities project delivery group. 3. A preliminary hazard analysis is performed on all work.	1. Environmental Group assumed design role and removes ES&H review from task. 2. Environmental Group approved work packages. 3. No preliminary hazard analysis was performed on construction task.	1. Design and ES&H reviews were not performed, contributing to the accident. 2. Construction packages were not approved by facilities group. 3. Hazards were not identified, contributing to the accident.
WHEN Occurred, identified, facility status, schedule				
WHERE Physical location, environmental conditions	Sump location was placed above a 13.2 kV electrical line.	Sump location is placed in a non-hazardous location.	Inadequate design allowed sump location to be placed above a 13.2 kV line.	Sump location was placed above an electrical line, which was contacted by a worker jackhammering in the area.
WHO Staff involved, training, qualification, supervision	Environmental Group assumes line responsibility for project.	Environmental Group serves as an oversight/support organization to assist line management in project.	Support organization takes responsibility of line function for project management.	Lack of oversight on project.
MANAGERIAL CONTROLS Control Chain Hazard Analysis Monitoring	Management allowed Environmental Group to oversee construction tasks.	Management assures that work is performed by qualified groups.	Hazards analysis was not conducted.	Hazards were not identified, contributing to the accident.
OTHER				

NOTE: The factors in this worksheet are only guidelines but are useful in directing lines of inquiry and analysis.

Table 7-5. Case Study: Change Analysis Summary.

Prior or Ideal Condition	Present Condition	Difference (Change)
Environmental Group serves as an oversight/support organization to assist line management in project.	Environmental Group assumed line responsibility for project.	Support organization takes responsibility for a line function.
Project design and ES&H reviews are performed by appropriate groups to ensure adequate review and the safety and health of employees.	Environmental Group assumed design role and removed ES&H review from task.	Design and ES&H reviews were not performed.
Construction packages are approved by facilities project delivery group	Environmental Group approved work packages.	Established review process was bypassed.
A preliminary hazard analysis is performed on all work.	No preliminary hazard analysis was performed on maintenance task.	Hazards associated with the work being performed were not identified. No review of as-built drawings. No excavation permit. No underground utility survey.
Sump location is placed in a non-hazardous designed location.	Sump location was placed above a 13.2 kV electrical line.	Inadequate design allowed sump location to be placed above a 13.2 kV line.

Note: Not recognizing the compounding of change (for example, a change that was instituted several years earlier coupled with a more recent change) is a potential deficiency of change analysis. It is incumbent upon the analyst to guard against this potential shortcoming by being aware of this and continuing to search for all changes that affected the accident.

7.3.4 Root Cause Analysis

TIP

Root cause analysis should be conducted for every occurrence, regardless of severity or complexity. Minor incidents often foreshadow more serious events.

Accidents, however serious, are symptoms of a larger problem within a system. Though accidents generally stem from many causal factors, correcting the symptoms of a problem does little to prevent the possibility of a similar or more severe accident. To identify and “treat” the true ailment in a system, the root causes of an accident must be identified. Root cause analysis is used in accident investigation to identify the most basic deficiencies, including those management systems that, if corrected, would prevent a recurrence of the accident. Simply stated, the root cause is the underlying reason that answers the investigators’ question, “Why?” In this way, root cause analysis does not only apply to a specific accident or occurrence, but is intended to have generic implications for lessons learned to a broad group of DOE sites and facilities.

Once several (or all) of the recommended core analytic techniques have been performed, the accident investigation board should have a broad understanding of the accident’s events and conditions, along with a fairly extensive list of suspected causal factors. A root cause analysis is performed to refine the list of causal factors and categorize each according to its significance and impact on the accident.

This section provides some examples of root cause analysis and discusses analytical tools that can help accident investigators determine the root causes of an accident. Root cause analysis is not an exact science and therefore requires a certain amount of judgment.

A “root cause” is a basic deficiency or failure in a process control system that, if eliminated or corrected, would systematically prevent an accident’s recurrence. Root cause analysis is designed to determine an accident’s root cause when it may not be immediately apparent. Root causes involve both local problems (localized) or problems within the entire system (systemic) that allow or create deficiencies which cause or could cause unwanted occurrences. Root cause analysis is a systematic process that uses discrepancies and related information gathered during an investigation to determine the underlying reasons for the discrepancies. In accident investigations finding root causes is pre-requisite to the development and implementation of corrective and preventive measures. The intent of this analysis is to identify and address only those root causes that can be controlled within the system being investigated. (This would exclude events or effects that cannot be reasonably anticipated or controlled, such as earthquakes, tornados, floods, and other natural disasters). Core analytic techniques, such as events and causal factors, change, and barrier analyses, provide answers to an investigator’s questions regarding what, when, where, who, and how. Root cause analysis is primarily performed to resolve the question, “Why?”

There may be more than one root cause of a particular accident, but probably not more than three or four. If more are thought to exist at the conclusion of the analysis, the board should re-examine the list of causal factors to determine which causes can be further combined to reflect more fundamental (root) causes.

TIP

In any accident, there may be a series of causal factors, one leading to another. One of the most important responsibilities of the investigation board is to pursue each factor in the series until the board is assured that actual root causes are identified. Regardless of which technique is used, the main focus of the board should be finding concise and valid root causes that address the fundamental system deficiencies that led to the accident.

To initiate a root cause analysis, the facts surrounding the accident must be known. In addition, the facts must be analyzed using other analytic methods to ascertain an initial list of causal factors. A rather exhaustive list of causal factors must be developed prior to the application of root cause analysis to ensure that final root causes are accurate and comprehensive.

TIP

If a root cause analysis is attempted before all the significant facts are known or the full spectrum of causal factors is determined, it is likely that the real root causes will not be discovered.

To acquire needed information, investigators should examine the evidence collected from the accident scene, witness statements, interviews, and facility documents to determine what information will be needed for the particular root cause technique they are performing.

Root cause analysis can be performed using computerized or manual techniques. Regardless of the method, the intent is to use a systematic process for identifying root causes.

Manual methods include tier diagramming and compliance/noncompliance. Each is effective as a systematic method for identifying root causes. However, the compliance/noncompliance method reflects the limited applicability of certain techniques and underscores the need for the board to select analytic methods commensurate with the accident's scope, complexity, and severity. Computerized techniques can be somewhat more sophisticated and generally speed the process of root cause identification. An overview of these methods is provided below.

Tier Diagraming. This technique borrows from the flowchart technique and is another graphical representation of investigation data. Generally, five tiers—from Tier 0 to Tier 4—are built using data collected during the investigation. Tier 0 consists of significant facts, including direct cause of an accident. Tiers 1, 2, and 3 are composed of contributing factors, which are added to the diagram in successive importance. Each tier builds on the data presented in the tier immediately preceding it. Finally, Tier 4 is developed from the contributing causes identified in Tier 3; it identifies the basic deficiency or deficiencies that, if corrected, would prevent recurrence of the accident.

TIP

The tier diagram is a recommended method for root causes analysis because it is easily understood and implemented and because it yields consistent results.

In brief, the analyst works from left to right and up through the tiers until a final top tier (root cause(s)) is ascertained. Each tier is dependent and specifically correlated to facts and causal factors listed in the one preceding it. Five tiers (0 through 4), constructed using data from the case study, are shown in Figure 7-7. Investigators may find it helpful or necessary to tailor this technique to the circumstances of the accident by modifying the number of tiers in the diagram to suit the investigation's needs. The case study data presented in the tier diagram results in a root cause of "management actions/awareness/ involvement/feedback."

Note that the tier diagram is simply an example and is not meant to imply that management systems must always be found to be a root cause of accidents. The board should work to rollup causal factors until root causes are identified, and critically examine the roll up to ensure that they do not make unwarranted extrapolations to inaccurate causes. Each step involved in constructing a tier diagram is described below.

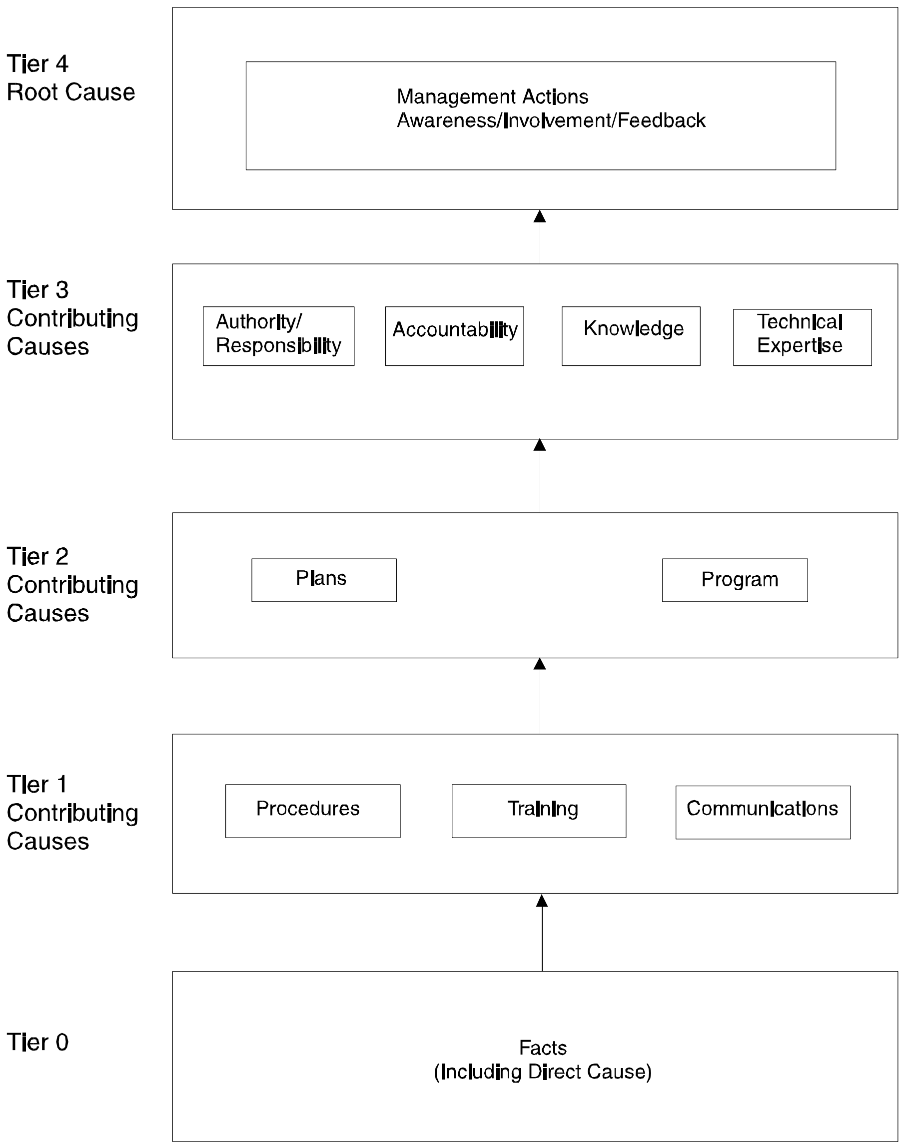

Figure 7-7. A tier diagram illustrates the contributing causes leading to a root cause.

Step 1: Construct Tier 0

The bottom tier, or foundation of the diagram, is constructed from all the significant facts of the accident, including the direct cause of the accident. For example, the direct cause of the case study accident is: "the jackhammer chisel bit contacted the energized 13.2 kV electrical cable." The tier diagram is then constructed as described below based on this direct cause, all the facts, and the results of the various causal factors analyses.

Step 2: Construct Tier 1

Tier 1 is composed of contributing causes related to procedures, training, and communications. These have a direct relationship to the accident and to the direct cause and significant facts listed in the bottom tier. Tier 1 can be established by asking the following questions:

- *Why did the jackhammer chisel bit contact the 13.2 kV electrical cable?* Because the design requirement for steel conduit was not implemented.

- *Why was an underground utility survey not conducted prior to excavation?* Because the utilities personnel did not believe that a survey would locate an underground electrical cable due to interference from the steel reinforcing rods imbedded in the concrete.

- *Why was a pre-job safety analysis not performed as required by procedures?* Because the Environmental Group (a support group) managing the construction project bypassed the construction safety procedures.

- *Why didn't the worker wear personal protective equipment?* Because he had not received training and the requirement had not been communicated by first-line supervision.

By using this method of systematic questioning, the first tier is constructed and becomes the basis for identifying more significant contributing causes in Tier 2.

Step 3: Construct Tier 2

More significant contributing causes are developed by examining data related to work plans and the overall program. By following a method similar to the questioning conducted in Tier 1 and maintaining cognizance of the Tier 1 components, a higher level of contributing causal factors can be identified. These can also be thought of as subcomponents of Tier 1 information. This tier provides more detail and an enhanced framework from which to work, further tailoring the diagram for analysis.

- *Why was the Environmental Group managing construction projects?* Because they had program and funding responsibility and assumed the responsibility for project management as well.

- *Why were the normal plans for managing construction projects not followed?* Because of schedule pressures, the Environmental Group developed an alternative procedure that bypassed the normal safety reviews to save time.

Once this tier has been constructed, the investigator selects components or subcomponents that do not appear to apply in a determination of root cause by considering each contributing causal factor, then eliminating those not considered relevant. The board should work together to make these determinations, eliminating components only after discussion.

Step 4: Construct Tier 3

Tier 3 is made up of the remaining components and subcomponents, which are the most significant contributing causes. These components are a further refinement of the process and focus on specific areas related to the accident. This tier focuses on authority/responsibility, accountability, knowledge, and technical expertise. Based on the first two tiers, higher-level contributing causes can be developed by again asking, “Why”?

- *Why was the Environmental Group allowed to manage construction projects without the requisite background, training, or experience in design and construction projects?* Because management did not challenge the change in project management responsibility and did not recognize the insufficient knowledge and technical expertise of the group assuming the responsibility.

- *Why were underground utility surveys not being conducted?* Because management was not being held accountable for implementing program plans and procedures.

When Tier 3 has been completed, the board decides whether any component of the diagram merits further investigation and analysis. Once the higher-level contributing causes have been established, root causes can be developed by continuing the same method of inquiry. Given that the Tier 3 contributing causes exist, why were they allowed to exist? The answers to these questions become the root cause or causes of the accident and are recorded in Tier 4.

Step 5: Construct Tier 4 (Root Causes)

Why did management allow the conditions identified in Tier 3 to exist? Root causes could reflect the following:

- *Why did management allow the change in project management to occur?* Because management was not sufficiently involved to understand the implications of the change.

- *Why did management allow safety reviews to be deleted?* Because management was not aware that the alternative procedures were being used that did not require a safety review, and did not understand the risks being taken as a result.

- *Why did management not know of the changes involving risks?* Because management was not getting feedback on what risks were inherent in the alternative procedures and management approaches being taken.

While this example is not intended to be exhaustive, it illustrates the technique. It also illustrates the level of detail required before the root cause analysis can be conducted successfully.

Compliance/Noncompliance. The compliance/noncompliance technique is useful when investigators suspect noncompliance to be a causal factor. This technique compares evidence collected against three categories of noncompliance to determine the root cause of a noncompliance issue. As illustrated in Table 7-6, these are: “Don’t Know,” “Can’t Comply,” and “Won’t Comply.” Examining only these three areas limits the application of this technique; however, in some circumstances, an accident investigation board may find the technique useful.

Table 7-6. Compliance/noncompliance Root Cause Model Categories.

Don't Know		Can't Comply		Won't Comply	
Never knew	This is often an indication of poor training or failure in a work system to disseminate guidance to the working level.	Scarce resources	Lack of funding is a common rebuttal to questions regarding noncompliance. However, resource allocation requires decision-making and priority- setting at some level of management. Boards should consider this line of inquiry when examining root causes pertaining to noncompliance issues.	No reward	An investigator may have to determine whether there is a benefit in complying with requirements or doing a job correctly. Perhaps there is no incentive to comply.
Forgot	This is usually a local, personal error. It does not reflect a systemic deficiency, but may indicate a need to increase frequency of training or to institute refresher training.	Don't know how	This issue focuses on lack of knowledge (i.e., the knowhow to get a job done).	No penalty	This issue focuses on whether sanctions can force compliance, if enforced.
Tasks implied	This is often a result of lack of experience or lack of detail in guidance.	Impossibility	This issue requires investigators to determine whether a task can be executed. Given adequate resources, knowledge, and willingness, is a worker or group able to meet a certain requirement?	Disagree	In some cases, individuals refuse to perform to a standard or comply with a requirement that they disagree with or think is impractical. Investigators will have to consider this in their collection of evidence and determination of root causes.

The basic steps for applying the compliance/ noncompliance technique are:

- Have a complete understanding of the facts relevant to the event
- Broadly categorize the noncompliance event
- Determine why the noncompliance occurred (i.e., the subcategory or underlying cause).

For example, investigators may use this technique to determine whether an injured worker was aware of particular safety requirements, and if not, why he or she was not (e.g., the worker didn't know the requirements, forgot, or lacked experience). If the worker was aware but was not able to comply, a second line of questioning can be pursued. Perhaps the worker could not comply because the facility did not supply personal protective equipment. Perhaps the worker would not comply in that he or she refused to wear the safety equipment. Lines of inquiry are pursued until investigators are assured that a root cause is identified.

Lines of questioning pertaining to the three compliance/noncompliance categories follow. However, it should be noted that these are merely guides; an accident investigation board should tailor the lines of inquiry to meet the specific needs and circumstances of the accident under investigation.

- **Don't Know:** Questions focus on whether an individual was aware of or had reason to be aware of certain procedures, policies, or requirements that were not complied with.
- **Can't Comply:** This category focuses on what the necessary resources are, where they come from, what it takes to get them, and whether personnel know what to do with the resources when they have them.
- **Won't Comply**: This line of inquiry focuses on conscious decisions to not follow specific guidance or perform to a certain standard.

By reviewing collected evidence, such as procedures, witness statements, and interview transcripts, against these three categories, investigators can pursue suspected compliance/noncompliance issues as root causal factors.

Although the compliance/noncompliance technique is limited in applicability, by systematically following these or similar lines of inquiry, investigators can identify root causes and needed corrective actions.

Automated Techniques. Several root cause analysis software packages are available for use in accident investigation. Generally, these methods prompt the investigator to systematically review investigation evidence and record data in the software package. These software packages use the entered data to construct a tree model of events and causes surrounding the accident. In comparison to the manual methods of root cause analysis and tree or other graphics construction, the computerized techniques are quite time-efficient. However, as with any software tool, the output is only as good as the input; therefore, a thorough understanding of the accident is required in order to use the software effectively.

Many of the software packages currently available can be initiated from both PC-based and Macintosh platforms. The Windows™ based software packages contain pulldown menus and employ the same use of intuitive icons and symbols found in many other computer programs. In a step-by-step process, the investigator is prompted to collect and enter data in the templates provided by the software. For example, an investigator may be prompted to select whether a problem (accident or component of an accident) to be solved is an event or condition that has existed over time. In selecting the "condition" option, he or she would be prompted through a series of questions designed to prevent a mishap occurrence; the "event" option would initiate a process of investigating an accident that has already occurred.

TIP
Analytical software packages can help the board:

- *Remain focused during the investigation*
- *Identify interrelationships among data*
- *Eliminate irrelevant data*
- *Identify all relevant causal factors (most significantly, root causes).*

The graphics design features of many of these software packages can also be quite useful to the accident investigation board. With little input, these software packages allow the user to construct preliminary trees or charts; when reviewed by investigators, these charts can illustrate gaps in information and guide them in collecting additional evidence.

It is worth underscoring the importance of solid facts collection. While useful, an analytic software package cannot replace the investigative efforts of the board. The quality of the results obtained from a software package is highly dependent on the skill, knowledge, and input of the analyst.

7.4 Using Advanced Analytic Methods

The four core techniques are easily understood and effectively applied to many Type A and B investigations, but the analysis of more complex accidents may have to be supplemented with more sophisticated techniques. These techniques require in-depth knowledge and specialized expertise beyond the scope of this workbook. However, several are discussed briefly here to ensure awareness of their applicability to the accident investigation process. The chairperson, board members, and any subject matter experts should determine which methods to employ, based on their familiarity with various methods and the severity and complexity of the accident.

7.4.1 Analytic Trees

Analytic tree analyses are well defined, useful methods that graphically depict, from beginning to end, the events and conditions preceding and immediately following an accident. An analytic tree is a means of organizing information that helps the investigator conduct a deductive analysis of any system (human, equipment, or environmental) to determine critical paths of success and failure. Results from this analysis identify the details and interrelationships that must be considered to prevent the oversights, errors, and omissions that lead to failures. In accident investigations, this type of analysis can consist of both failure paths and success paths, and can lead to neutral, negative, or positive conclusions regarding accident severity.

TIP
An analytic tree enables the user to:

- *Systematically identify the possible paths from events to outcome*
- *Display a graphical record of the analytical process*
- *Identify management system weaknesses and strengths.*

The analytic tree process begins by clearly defining the accident; "branches" of the tree are constructed using logic symbology. Following is a summary overview of the approach to constructing an analytic tree, which is illustrated in Figure 7-8. It should not be inferred that this is the only way to construct or use analytic trees, since a variety of analytic tree methods is available.

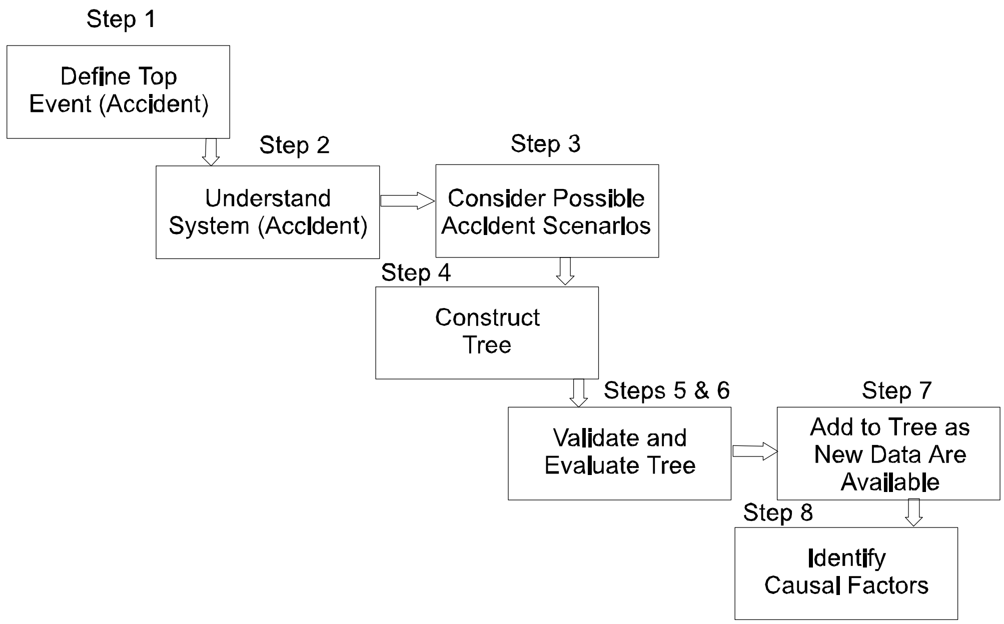

Figure 7-8. The analytic tree process begins with the accident as the top event.

As the events at the bottom branches of the tree become more specific, the causal factors of the accident are developed. When the event at the bottom contains no other events that allowed it to occur, a decision must be made regarding whether the event is a causal factor or is not relevant to the outcome of the accident (top event). When processed through the logic gate, each bottom tier should be necessary and sufficient to lead directly to failure or success of the event on the next higher tier.

The steps required to prepare an analytic tree are described below.

Step 1. Define the top event as the accident. As in events and causal factors analysis, the event should be defined as a single, discrete event, such as "worker strikes 13.2 kV primary feeder cable".

Step 2. Acquire a working knowledge of the accident effects, the work situation, and the upstream processes that preceded them. A comprehensive understanding of the management system is also needed to develop the tree.

Step 3. Based on the facts, postulate the possible scenarios by which the accident occurred. All accidents are complex events that become interrelated to produce the unwanted event (accident). This step should force the investigator to analyze the facts of the accident and try to visualize all possible scenarios. As the investigation continues and as new evidence is introduced, a different scenario could develop. Before the tree is constructed, it is important to visualize it using different possible scenarios consistent with the facts.

Step 4. Construct the analytic tree, starting with the top event and using the proper logic gates and symbols. The tiers beneath the top event should explain the reason for failure or success of that event. The proper use of symbols and transfers is crucial to understanding this graphic model.

Step 5. It is important for each board member to validate the analytical tree for completeness, logic, and accuracy. As new facts and evidence are discovered, the tree must be updated to reflect these changes. The validation process should begin as soon as the tree is constructed. The purpose of this validation review is to confirm that:

- The tree meets its intended objectives.
- The management systems are fully and clearly described.
- Inputs to logic gates are necessary and sufficient to logically produce the stated output events.

Step 6. Each relationship between events should be evaluated to determine the causal factors of the accident (top event). As these tiers flow down to the end events, the analytic tree specific events will be developed and will help describe why the top event occurred, by organizing the accident's evidence in a way that helps the board identify the accident's causal factors. Though the chart is highly structured, identifying root causes is not a mechanical process. Considerable reasoning and judgment are required from the board to determine root and contributing causes.

Step 7. Add to the analytic tree as new evidence is acquired and new possible scenarios are developed. The tree must be a working analytical tool that will have several iterations before the final tree is developed. If new possible scenarios are introduced, do not reject the scenario if it does not fit the tree. It might be necessary to construct a new tree for a new scenario. It is important that all possible scenarios be considered; they should be rejected only because they do not fit the facts, not because they are improbable.

Step 8. Through the process of fact-finding and analysis, develop the scenario or scenarios that correlate to the facts and to the analyses from other analytical tools.

The basic conventions for constructing an analytic tree are to:

- Use common and accepted graphic symbols for events, logic gates, and transfers. (Figure 7-9 displays the symbols used in analytic trees.)
- The analytic tree should be constructed as simply as the accident allows. The tree should flow logically from the top event to the more specific events. If an event occurs that has no relevance to the accident, a diamond symbol should note that there is no further development of this event.
- Keep the tree logical. The tree should be validated at each level to ensure that each contributing event logically proceeds to the top event. The lower-tier input events should be only those that are necessary and sufficient to produce the next tier event. It is important for events to logically flow to other events that are supported by the facts.

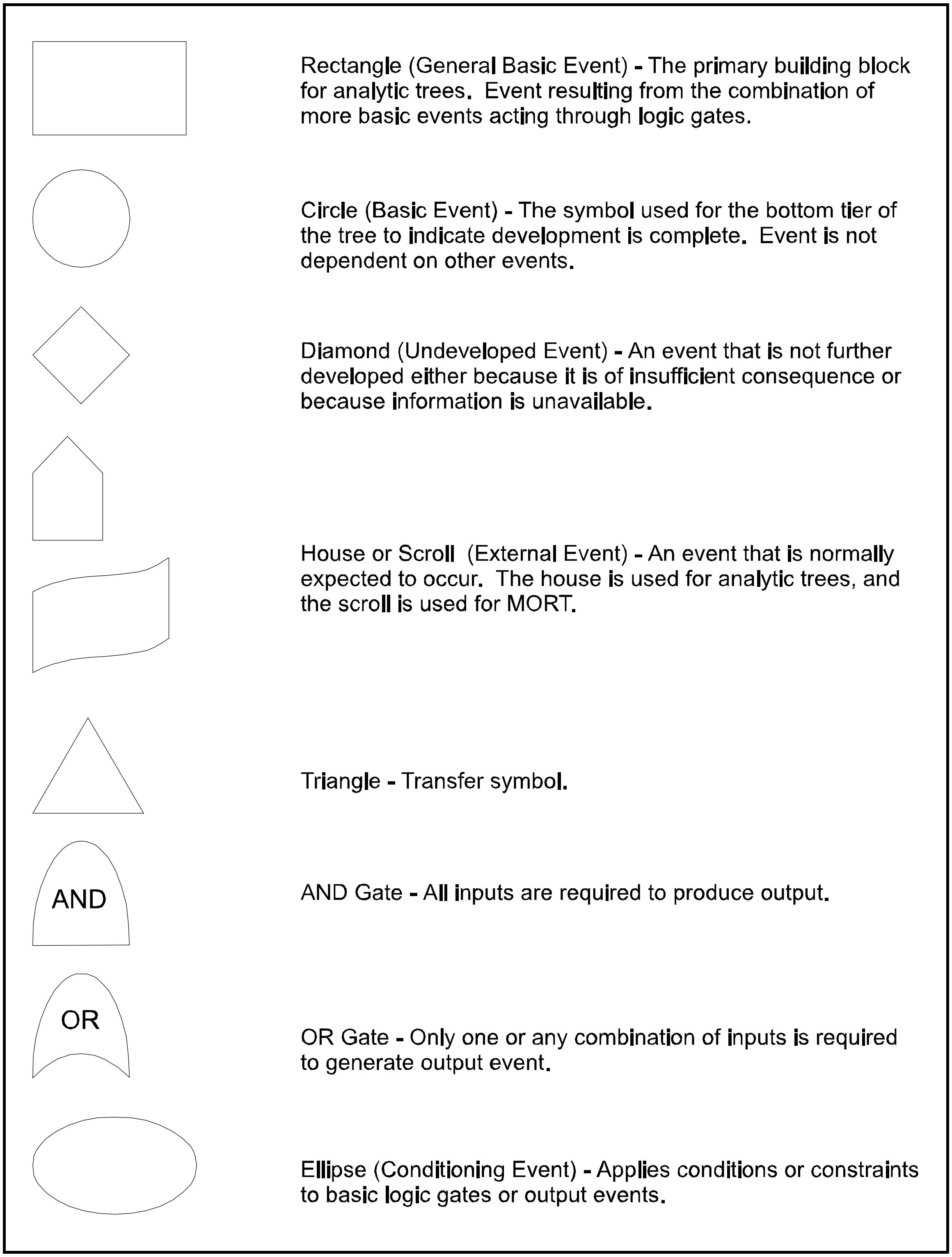

Figure 7-9. Analytic trees are constructed using symbols.

- Use the proper logic gate that describes the relationship between the events. The proper selection and use of the logic gates will identify the interaction between lower-tier events and the top event.

- The event descriptions should be simple, clear, and concise. The descriptions should be sufficiently detailed and logical that they can be understood without referring to another section.

- The final analytic tree should be limited in the number of tiers placed on a single page. For legibility and readability, it is best that only four or five tiers be placed on a single page.

- Use a common numbering system for the events. Each event is identified by the decimal numbering system. The number of digits in the decimal event numbering system should correspond to the tier on which the event is located. The fourth tier will contain four digits. This system for numbering will uniquely describe an event and systematically trace its development through subbranches and branches to the first-tier event. Each successively higher-level event can be identified by dropping the last digit from the number as shown below:

	Top Event
1	First Tier
1.1	Second Tier
1.1.1	Third Tier
1.1.1.1	Fourth Tier
1.1.1.1.1	Fifth Tier

- A modified decimal system for numbering events can be adapted for transfer symbols, beginning with the letter designation for the transfer. If the transfer number is A, then the corresponding numbers could be A.1.3.2. The numbering system is the same as the decimal system, with an alphabetic symbol as the first digit corresponding to the transfer. The fourth subtier that is transferred would be labeled as shown below:

D	Transfer
D.2	First Subtier
D.2.2	Second Subtier
D.2.2.1	Third Subtier
D.2.2.1.2	Fourth Subtier

- Use transfers to avoid duplication of identical branches or segments of the tree and to reduce single-page tree complexity. Whenever two or more gate output events have identical details in the substructures contributing to their occurrence, that substructure should be constructed under only one of the output events; it should then be transferred to the others through the use of transfer symbols. The event must be identical to be transferrable. Transfers should also be used below the bottom-tier events on a page to indicate continuance of subbranches of those events on other pages. Whenever there is insufficient space on a page to develop a branch below an event at any level, a transfer immediately below that event indicates that the branch is developed on another page.

- Do not number or letter logic gates; use numeric and alphanumeric decimal identification designations only for events.

- Follow the left-to-right convention of indicating time sequencing or order of performance for related events on a single tier. It should also be apparent that a higher-tier event has greater significance (more impact on the top event) and occurs later than the more detailed contributory events located on lower tiers within its branch.

Figure 7-10 shows an example format for the layout of an analytic tree. Although each accident will dictate its own shape, this example displays all elements in an analytic tree. Figure 7-11 is an example of a completed analytic tree for a grinding wheel accident. The lowest tier shows that the tool rest was not set correctly, the operator did not wear goggles, and the machine guard was removed for convenience. This example displays how the lower-tier elements contribute (flow) to the top event.

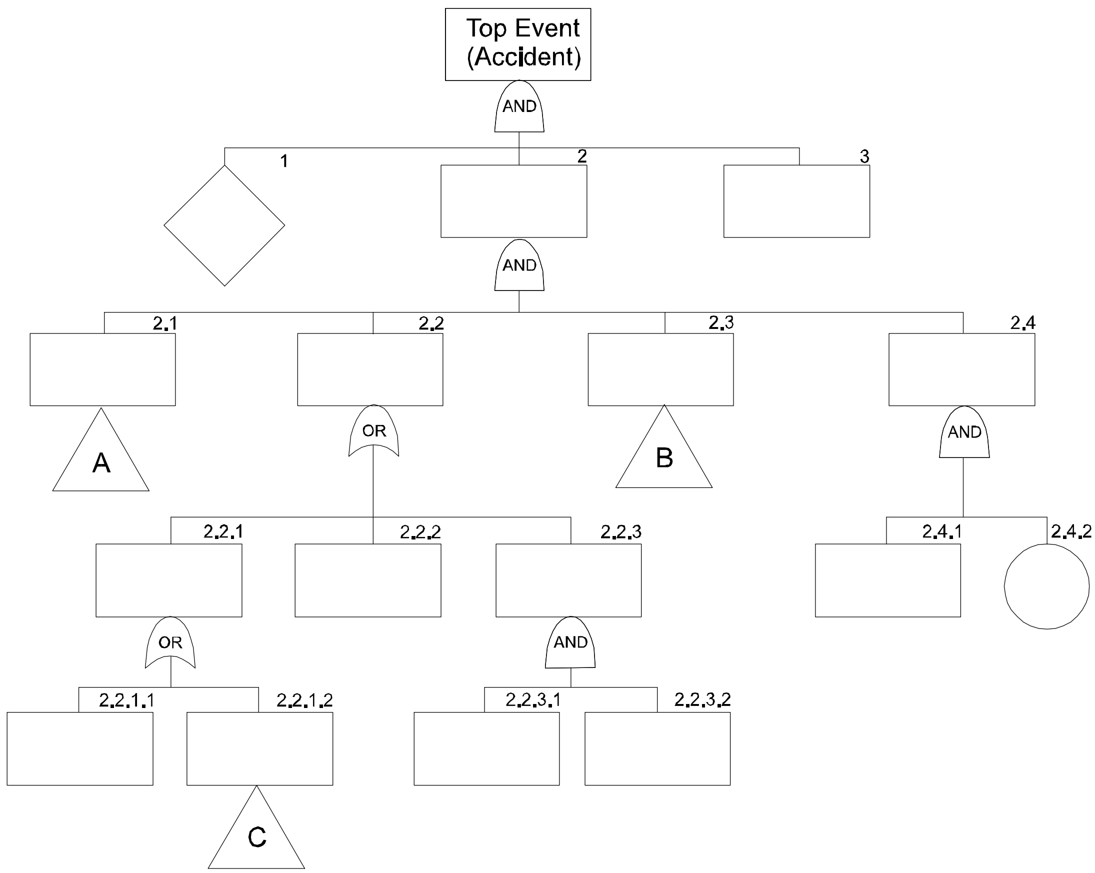

Figure 7-10. The layout of an analytic tree shows logical relationships.

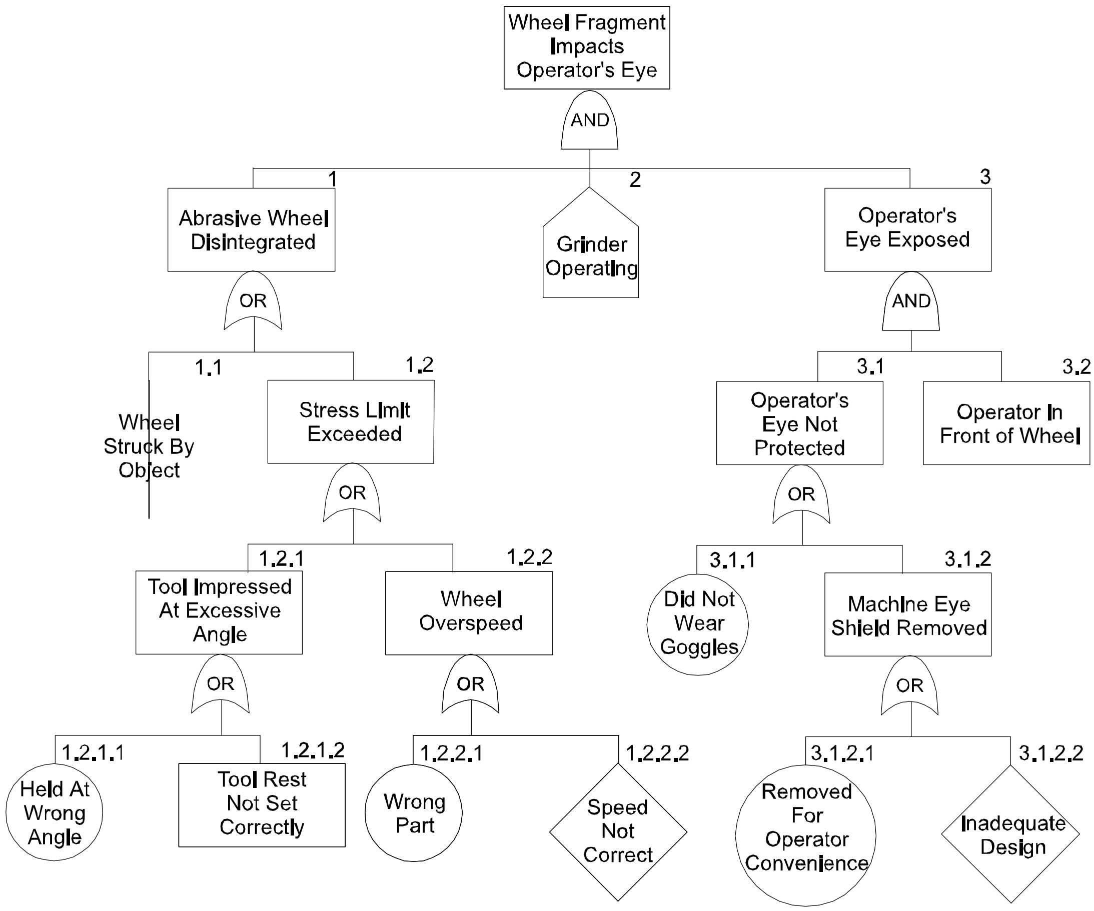

Figure 7-11. A completed analytic tree shows the flow of lower-tier elements to the top event.

7.4.2 Management Oversight and Risk Tree Analysis (MORT)

MORT—a comprehensive analytical tree technique—was originally developed for DOE to help conduct nuclear criticality and hardware analysis. It was later adapted for use in accident investigations and risk assessments. Basically, MORT is a graphical checklist, but unlike the events and causal factors chart, which must be filled in by investigators, the MORT chart contains generic questions that investigators attempt to answer using available factual data. This enables the investigator to focus on potential key causal factors. The MORT chart's size can be difficult to learn and use effectively. For complex accidents involving multiple systems, such as nuclear systems failures, MORT can be a valuable tool but may be inappropriate for relatively simple accidents. MORT requires extensive training to effectively perform an in-depth causal analysis of complex accidents. If needed, the MORT analysis is usually performed by board members with substantial previous experience in using the MORT techniques.

*The **benefits** of MORT are that it:*

- *Uses the analytic tree method to systematically dissect an accident*
- *Serves as a detailed road map by requiring investigators to examine all possible causal factors (e.g., assumed risk, management controls or lack of controls, and operator error)*
- *Looks beyond immediate causes of an accident and instead stresses close scrutiny of management systems that enabled the accident to occur*
- *Permits the simultaneous evaluation of multiple accident causes through the analytic tree.*

In evaluating accidents, MORT provides a systematic method (analytic tree) for planning, organizing, and conducting a comprehensive accident investigation. Through MORT analysis, investigators identify deficiencies in specific control factors and in management system factors. These factors are evaluated and analyzed to identify the causal factors of the accident.

Detailed knowledge and understanding of management and operating systems is a prerequisite to a comprehensive MORT analysis. Therefore, it is most effective if investigators have collected substantial evidence before initiating the MORT process. The management system data required include procedures, policies, implementation plans, risk assessment program, and personnel. Information about the facility, operating systems, and equipment is also needed. This information can be obtained through reviews of physical evidence, interview transcripts, management systems, and policies and procedures.

The symbols used on the MORT chart are similar to those used for other analytical trees. The symbols that differ for the MORT chart are the scroll (“normally expected” event) and the oval (“satisfactory” event). The “normally expected” event distinguishes events that are typically a part of any system, such as change and normal variability. The “satisfactory” event describes events that may be accident causal factors but are a necessary part of the operation, such as “functional” (part of the system) and people or objects in the energy channel. In addition to using the traditional transfer symbol (triangle), the MORT chart includes capital letters as drafting breaks and small ovals as risk transfers.

The first step of the process is to obtain the MORT charts and select the MORT chart for the safety program area of interest evaluating each event. Next, the investigators work their way down through the tree, level by level, proceeding from known to unknown. Events should be coded in a specific color relative to the significance of the event (accident). The color-coding system used in MORT analysis is shown in Table 7-7. An event that is deficient, or less than adequate (LTA) in MORT terminology, is marked red. The symbol is circled if suspect or coded in red if confirmed. An event that is satisfactory is marked green in the same manner. Unknowns are marked in blue, being circled initially and colored in if sufficient data do not become available, and an assumption must be made to continue or conclude the analysis.

It is not useful to start on the first day by marking everything as needing more information (color-coded blue). Instead, start marking the first MORT chart with red and black for events where there is sufficient evidence. Ideally, all blue blocks eventually are replaced by one of the other colors; however, this may not always be possible.

Table 7-7. MORT Color Coding System.

Color Code	Significance
Red	The event is less than adequate. Corrective actions are needed. All events colored red must be documented and supported with facts
Green	The event is satisfactory and adequate. Credible evidence must support this event to ensure that no corrective actions need to be identified for this event.
Blue	The event has insufficient evidence or information to evaluate. Additional facts or evidence must be collected to analyze this event.
Black	The event is not applicable or relevant to the accident. The event does not need any further investigation.

When the appropriate segments of the tree have been completed, the path of cause and effect (from lack of control by management, to basic causes, contributory causes, and root causes) can easily be traced back through the tree. This becomes a matter of following the red events through the various logic gates. The tree highlights quite clearly where controls and corrective actions are needed and can be effective in preventing recurrence of the accident.

Figures 7-12 through 7-14 show three MORT charts. Figure 7-12 displays the injury, damage, other costs, performance lost, or degraded event. Figure 7-13 describes the incident, barriers, and persons or objects. Figure 7-14 is an evaluation of the management system factors.

7.4.3 Project Evaluation Tree (PET) Analysis

PET is an efficient means of performing an in-depth analysis of an operation, project, or system. This analytical tree method is best suited for performing hazard and accident analyses, but it can also be used to identify preventive measures. PET was developed to capture the philosophy and methodology of MORT, but eliminate the complexity of the more than 1500 logic gates in MORT.

Using PET in an accident investigation requires detailed information regarding the various components of the system, operation, or accident situation, such as procedures, personnel, facilities, and equipment. Using logic symbology, an analyst traces each component of a system through the tree's branches to evaluate each element as a potential causal factor.

TIP

The key benefits of the PET analysis are that it:

- *Provides a simplified approach that applies the tenets of MORT*
- *Categorizes information into three main branches—procedures, personnel, and plant or hardware—enabling investigators to examine the factors that impact an accident relatively simply and quickly.*

Figure 7-12. The initial MORT chart uses logic symbols.

Figure 7-13. The accident description can be shown on a MORT chart.

Figure 7-14. Management system factors can be shown on a MORT chart.

PET is structured for evaluation and analysis of procedures, personnel, and facilities/hardware. (An example of a PET chart used to analyze procedures is shown in Figure 7-15.) PET analysis requires detailed information on these three dimensions. Evaluation of procedures requires procedural instructions, reviews and safety evaluations, workplans, work package instructions, and other data. Personnel evaluation requires job descriptions, organizational charts, training records, course curricula, course materials, interviews, and other data. If the accident was facility- or hardware-related, then drawings, procurement documents, specifications, test plans, system safety plans, hazard analyses, and budget data are required to conduct a comprehensive PET analysis. The scope and depth of the accident investigation dictate the input requirements.

The first step is to organize the data into procedures, personnel, and facilities/hardware. These data are then systematically evaluated using the appropriate PET chart. The next step is to color-code the events. Red is used for events that are less than adequate (LTA), green for events that are satisfactory (adequate), black for events that are not relevant to the accident, and blue to indicate areas that need additional investigation or analysis to reach a decision. (This color-coding system is the same system used for MORT.)

After the chart is completed and the events are color-coded, PET worksheets should be used to evaluate each red item. A PET analysis worksheet is provided at the end of this section. This worksheet is similar to the barrier analysis and change analysis worksheets. It provides the basis for the narrative summary of the analysis.

7.5 Other Analytic Techniques

Other analytic techniques may be used for specific investigations, depending on the nature and complexity of the accident. Ultimately, the analytic techniques used in any investigation should be determined by the board chairperson with input from the board members and advisors/consultants. To conduct an effective and timely investigation, the choice normally should be limited to the techniques discussed above. However, if warranted by the circumstances of the accident investigation, experts in various analytic methods may be called upon to use other analytic techniques. It is also important for investigators to understand that many of these analytical processes may have been completed prior to the accident and may be included in authorization basis documentation (e.g., safety analysis reports). This information is useful to the board in developing and understanding its own analysis of the accident. Following are brief descriptions of additional analytic techniques that might be used.

7.5.1 Time Loss Analysis

Time loss analysis evaluates emergency response performance. The basic assumption of this technique is that every accident sequence has a natural progression that would occur without outside intervention by emergency response personnel (e.g., a fire would eventually burn out without the aid of firefighters).

Figure 7-15. This branch of the PET chart deals with procedures.

With this technique, the natural course of accident events is plotted graphically against time. A second line is plotted that shows the positive effect of emergency responders on the natural course of events (i.e., decreasing the end-time of the accident). A second line also can be plotted that displays emergency response actions that made the natural course of events worse or prolonged the end-time of the accident (for example, by contributing to additional injuries). This technique begins with the accident, compares actual events and processes with an ideal response process, and continues until loss ceases.

Time loss analysis is not widely used in accident investigations; however, it can be useful in cases where additional response activities could have decreased the severity of the accident or where investigators suspect that emergency response actions were less than sufficient. Figure 7-16 displays a time loss analysis chart.

7.5.2 Human Factors Analysis

Human factors analysis identifies elements that influence task performance, focusing on operability, work environment, and management elements. Humans are often the weakest link in a system and can be the system component most likely to fail. Often machines are not optimally designed for operators, thereby increasing the risk of error. High-stress situations can cause personnel fatigue and increase the likelihood of error and failure. Therefore, methods that focus on human factors are useful when human error is determined to be a direct or contributing cause of an accident.

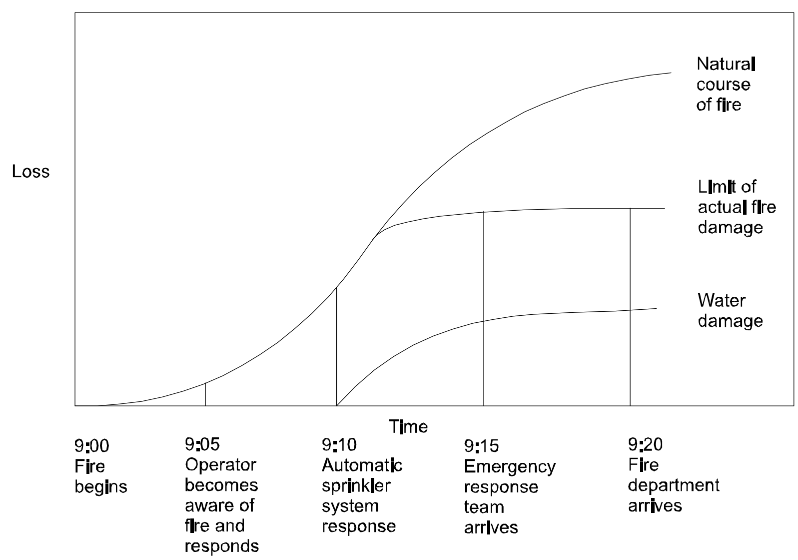

Figure 7-16. Time loss analysis can be used when emergency response is in question.

7.5.3 Integrated Accident Event Matrix

An integrated accident event matrix illustrates the time-based interaction between the victim and other key personnel prior to the accident and between the emergency responders and the victim after the accident. It analyzes at what time key personnel performed certain tasks both before and after the accident. This technique complements the events and causal factors chart, but is more specific about the timing of accident events; it is a simple and effective way to develop the accident scenario around the facts related to key personnel and appropriate tasks.

7.5.4 Failure Modes and Effects Analysis

This method is most often used in the hazard analysis of systems and subsystems; it is primarily concerned with evaluating single-point failures, probability of accidents or occurrences, and reliability of systems and subsystems. This technique examines a system's individual subsystems, assemblies, and components to determine the variety of ways each component could fail and the effect of a particular failure on other equipment components or subsystems. If possible, the analysis should include quantified reliability data.

7.5.5 Software Hazards Analysis

This analytic technique is used to locate software-based failures that could have contributed to an accident. This technique may be increasingly important in the future as more operations and systems associated with an accident become computerized and therefore dependent on software.

7.5.6 Common Cause Failure Analysis

Common cause failure analysis evaluates multiple failures that may be caused by a single event shared by multiple components. Common causes of failures in redundant systems are analyzed to determine whether the same failure contributed to the accident. The general approach to common cause failure analysis is to identify critical systems or components and then use barrier analysis to evaluate the vulnerability to common environmental hazards, unwanted energy flows, and barrier failures. This method is useful for accidents in which multiple barriers failed and a common cause failure contributed to the accident.

7.5.7 Sneak Circuit Analysis

A sneak circuit is an unanticipated energy path that can enable a failure, prevent a wanted function, or produce a mistiming of system functions. Sneak circuit analysis is mainly performed on electronic circuitry, but it can also be used in situations involving hydraulic, pneumatic, mechanical, and software systems. It identifies ways in which built-in design characteristics enable an undesired function to occur or prevent desired functions from occurring. Its importance lies in the distinction from component failure. Sneak circuit failure results from circuit design. Sneak circuit analysis generally employs inductive reasoning and is difficult to employ without the appropriate proprietary software.

7.5.8 Materials and Structural Analysis

Materials and structural analysis is used to test and analyze physical evidence. This technique has made significant contributions to developing credible scenarios and determining the cause of several accidents. It is used whenever hardware, material failure, or structural integrity is a possible issue, but the cause of the failure is unknown.

7.5.9 Design Criteria Analysis

This method involves the systematic review of standards, codes, design specifications, procedures, and policies relevant to the accident. This tool is useful in identifying whether codes exist, how standards or codes were circumvented, and codes or standards that should be in place to prevent recurrence.

7.5.10 Accident Reconstruction

Although not widely used in DOE accident investigations, accident reconstruction may be useful when accident scenes yield sketchy, nonconclusive evidence. This method uses modeling to reconstruct the accident-related equipment or systems (i.e., from accident to pre-accident state). Good reconstruction can be more accurate than witness statements, because it applies the laws of physics and engineering science.

7.5.11 Scientific Modeling

Scientific modeling models the behavior of a physical process or phenomena. The methods, which range from simple hand calculations to complex and highly specialized computer models, cover a wide spectrum of physical processes (e.g., nuclear criticality, atmospheric dispersion, groundwater and surface water transport/dispersion, nuclear reactor physics, fire modeling, chemical reaction modeling, explosive modeling). For example, several computer models have been developed to predict the concentrations of hazardous materials in the air at downwind locations from a release. Such modeling is useful in characterizing the consequences of an accidental release of a hazardous material to the atmosphere. Similarly, nuclear criticality models (e.g., the SCALE package or the KENO code) can analyze scenarios that could lead to a critical configuration. In the event of a nuclear criticality, such models could be useful in understanding how the event occurred and what factors were important to the accident scenario (e.g., the presence of “moderating” or “reflecting” materials, such as water, can be very important).

Although useful in some circumstances, scientific modeling is not necessary for most accident investigations. It is only performed for accident scenarios involving complex physical processes (e.g., nuclear criticality, fires, “runaway” chemical reactions and explosions) and is not normally needed for typical occupational and industrial accidents. When scientific modeling is deemed appropriate, it should be performed at the direction of technically competent personnel (e.g., specialists, consultants, or board members who have the requisite technical backgrounds and familiarity with the models being used).

All scientific models have inherent assumptions and uncertainties that limit their accuracy. The board should recognize such limitations when considering the results of scientific models during the accident investigation process. Sometimes the facility in which an accident occurred may choose to perform scientific modeling and may provide those results to the board. In reviewing such results, the board should validate whether it is appropriate to obtain independent expertise to interpret the results and determine the validity of the modeling assumptions.

7.6 Determining Causal Factors

> ***TIP***
> *The process of determining causal factors seeks to answer the questions — what happened and why did it happen?*

Causal factors are events and conditions that are necessary to produce or contribute to the unwanted event (accident). There are three types of causal factors:

- Direct cause
- Contributing causes
- Root causes.

7.6.1 Direct Cause

The direct cause of an accident is the immediate event or condition that caused the accident. Each direct cause should be stated in one sentence, as illustrated in the examples below.

> **EXAMPLES:**
> **ACCIDENT DIRECT CAUSES**
>
> - The direct cause of the accident was contact between the chisel bit of the air-powered jackhammer and the 13.2-kV energized electrical cable in the sump pit being excavated.
> - The direct cause of the fatal accident was the fall from an unprotected platform.

7.6.2 Contributing Causes

Contributing causes are events or conditions that increase the likelihood of an accident but that individually did not cause the accident. Contributing causes may be based on longstanding conditions or a series of prior events that, while not important in and of themselves, collectively increased the probability that an accident would occur.

> **EXAMPLES:**
> **ACCIDENT CONTRIBUTING CAUSES**
>
> - Failure to implement safety procedures in effect for the project contributed to the accident.
> - Failure to erect barriers or post warning signs contributed to the accident.
> - The standing work order process was used by facility personnel as a convenient method of performing work without a job ticket and work package, allowing most work to be field-directed.
> - Inadequate illumination in the area of the platform created visibility problems that contributed to the fall from the platform.

7.6.3 Root Causes

Root causes are the most basic events or conditions that, if eliminated or modified, would keep the accident from recurring. Root causes are derived from and generally encompass several contributing causes. They are higher-order, fundamental causal factors that address classes of deficiencies, rather than single problems or faults. They are identified using root cause analysis (see Section 7.3.4). In many cases, root causes relate directly to DOE's guiding principles of safety management. Root causes, as shown in the examples below, should focus on a single DOE or contractor line organization, management system, or safety system so that they can be easily understood.

Root causes can include system deficiencies, management failures, inadequate competencies, accepted risks, performance errors, omissions, non-adherence to procedures, and inadequate organizational communication.

> **EXAMPLES:**
> **ACCIDENT ROOT CAUSES**

- Contractor management failed to implement contractual requirements that defined responsibility and accountability for safety. These responsibilities were not exercised prior to the accident.
- Using the standing work order process, normally used for routine tasks, to accomplish nonroutine, complex modification and construction work was a root cause of the accident.
- Management systems were not effective in correcting longstanding, well defined programmatic weaknesses identified through internal and external assessments, past occurrences, and previous accident investigations or in translating lessons learned into safe day-to-day operations at the facility.
- Management failed to implement existing requirements that would have mitigated the hazards involved in the accident.

It cannot be overemphasized that the primary purpose of any accident investigation is to prevent recurrence through the identification and correction of root causes. Therefore, it is important for boards to avoid ending investigations before the root causes are identified. Instead, the board must continue to ask, "Why?" If a board cannot identify root causes, this should be stated clearly in the investigation report, along with an explanation.

TIP

Even though the board should avoid placing individual blame for an accident, the board has an obligation to seek out and report all causal factors, including deficiencies in management or safety systems.

KEY POINTS TO REMEMBER

Determining Facts

- Begin defining facts early in the collection of evidence.
- Develop an accident chronology (e.g., events and causal factors chart) while collecting evidence.
- Set aside preconceived notions and speculation.
- Allow the discovery of facts to guide the investigative process.
- Consider all information for relevance and possible causation.
- Continually review facts to verify accuracy and relevance.
- Retain all information gathered, even that which is removed from the accident chronology.
- Establish a clear description of the accident.

Conducting the Analysis

Four core analytic techniques are generally used in DOE accident investigations:

- **Events and causal factors analysis:** used to trace the sequence of events surrounding an accident, as well as the conditions present for the accident to occur
- **Barrier analysis:** used to examine the effectiveness of three types of barriers (administrative, supervisory/management, and physical) intended to protect persons, property objects, and the environment from unwanted energy transfers
- **Change analysis:** used to examine planned or unplanned changes in a system and determine their significance as causal factors in an accident
- **Root cause analysis:** used to identify the most basic deficiencies, including management systems, that, if corrected, would prevent a recurrence of the accident.

Each of these techniques has strengths and limitations that should be reviewed before applying it to any given accident. However, the use of the core analytical techniques should be sufficient for most accident investigations. Other techniques are available for complex accidents or when there are special circumstances or considerations. Some of these techniques are MORT, PET, materials and structural analysis, design criteria analysis, integrated accident event matrix, and scientific modeling.

Analytical techniques are used to determine the causes of an accident. There are three types of causal factors: the **direct cause**, **contributing causes**, and **root causes**.

Other techniques are available for complex accidents or special accident circumstances.

The following should be considered when performing analyses:

- Chart events in chronological order, developing an events and causal factors chart as initial facts become available.
- Stress aspects of the accident that may be causal factors.
- Establish accurate, complete, and substantive information that can be used to support the analysis and determine the causal factors of the accident.
- Stress aspects of the accident that may be the foundation for judgments of need and future preventive measures.
- Resolve matters of speculation and disputed facts through board discussions.
- Document methodologies used in analysis; use several techniques to explore various components of an accident.
- Qualify facts and subsequent analysis that cannot be determined with relative certainty.
- Conduct preliminary analyses; use results to guide additional collection of evidence.
- Analyze relationships of event causes.
- Clearly identify all causal factors.
- Examine management systems as potential causal factors.
- Consider the use of investigation and analytic software to assist in evidence analysis.

Barrier Analysis Worksheet

Hazard	Direct Barrier or Control Failure	Possible Contributing Factors to Barrier or Control Failures	Possible Root Causes of Failures	Loss or Potential Loss Event	Evaluation

Change Analysis Worksheet

Factors	Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
WHAT Conditions, occurrences, activities, equipment				
WHEN Occurred, identified, facility status, schedule				
WHERE Physical location, environmental conditions				
WHO Staff involved, training, qualification, supervision				
MANAGERIAL CONTROLS Control Chain Hazard Analysis Monitoring				
Other				

NOTE: The factors in this worksheet are only guidelines but are useful in directing lines of inquiry and analysis.

PET Analysis Worksheet

Prepared by: ______________________________

Date: ______________________________

Accident Investigation: ______________________________

Item No.	Item Evaluated	PET Event	Color	Problem/Comments	Responsible Person/Agency	Status	Final Completion Date